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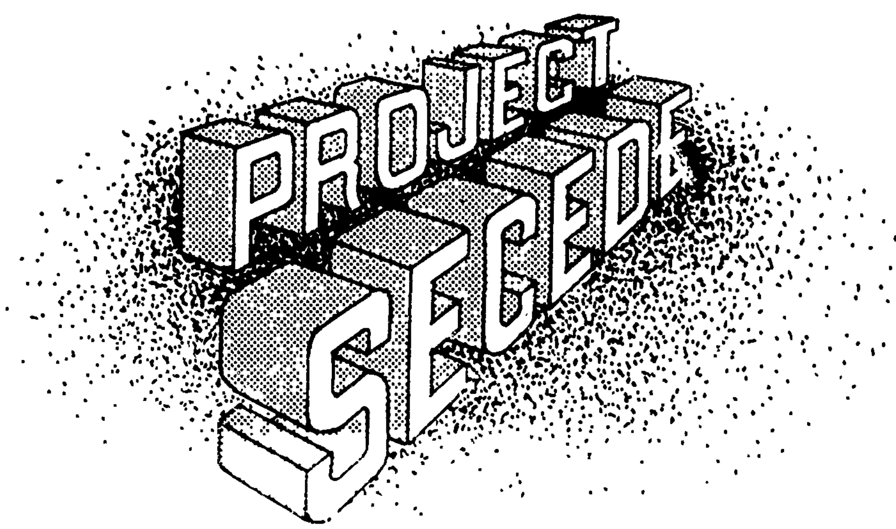

SECEDE II CHEMICAL PAYLOADS

Thiokol Chemical Corp., Astro-Met Plant

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13. ABSTRACT

For the SECEDE II operation, six barium vapor release payloads were successfully launched on rocket vehicles during the months of January and February, 1971, at Eglin Air Force Base, Florida.

The SECEDE II payload matrix included barium vapor releases based on several chemical thermite weights including five each 48-kg releases, three each 1-kg releases, one 320-kg release, and one 16-kg release. (The last two resulted from a malfunction of the 352-kg Olive Payload.) With the exception of the 1-kg releases, all releases were made by simultaneous ignition of a number of canisters each containing 16-kg of thermite. Altitude effects were studied by making 48-kg releases at 150, 185, and 250 km, with 185 km as the primary release altitude.

Barium vapor was produced by the exothermic reaction of a pressed mixture of barium metal chips and cupric oxide powder. The mixture ratio was 2.5 moles of barium per mole of cupric oxide with an addition of 1.8 percent by weight barium azide.

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SECEDE II CHEMICAL PAYLOADS

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Ray N. Bybee

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PUBLICATION REVIEW

This technical report has been reviewed and is approved.

RADC Project Engineer	Richard W. Carman RADC Contract Engineer

FOREWORD

This report presents a description of launch operations for the barium payloads during the SECEDE II operation conducted at Eglin Air Force Base, Test Site 15A, under Contract RADC F-30602-69-C-0030. The chemical payloads were furnished by Thiokol Chemical Corporation, Astro-Met Plant, Ogden, Utah. Sandia Laboratories, Albuquerque, New Mexico, provided the rocket vehicles and test facilities for the environmental tests conducted on the 352-kg payload. Eglin Air Force Base, Test Site 15A launching facilities were used to launch all payloads.

Field operations were completed during the period 4 January through 3 February 1971.

ABSTRACT

For the SECEDE II operation, six barium vapor release payloads were successfully launched on rocket vehicles during the months of January and February, 1971, at Eglin Air Force Base, Florida.

The SECEDE II payload matrix included barium vapor releases based on several chemical thermite weights including five each 48-kg releases, three each 1-kg releases, one 320-kg release, and one 16-kg release. (The last two resulted from a malfunction of the 352-kg Olive payloads.) With the exception of the 1-kg releases, all releases were made by simultaneous ignition of a number of canisters each containing 16-kg of thermite. Altitude effects were studied by making 48-kg releases at 150, 185, and 250 km, with 185 km as the primary release altitude.

Barium vapor was produced by the exothermic reaction of a pressed mixture of barium metal chips and cupric oxide powder. The mixture ratio was 2.5 moles of barium per mole of cupric oxide with an addition of 1.8 percent by weight barium azide.

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INTRODUCTION

As part of a continuing series of barium vapor release programs, the Strategic Technology Office of the Advanced Research Projects Agency (ARPA) sponsored the SECEDE II field tests conducted at Eglin Air Force Base, Florida in the first two months of 1971. Under a contract from the Rome Air Development Center (RADC), Thiokol Chemical Corporation, Astro-Met Plant, produced six rocket payloads to release the barium vapor clouds. Original test planning called for a matrix as listed in the following table.

Payload Name	Mass of Barium Thermite	Release Altitude	
Nutmeg	48 kg Ba + 1 kg Ba	150 km	(3)
Olive	352 kg Ba	185 km	
Plum	48 kg Ba + 1 kg Ba	185 km	(3)
Quince	48 kg Ba + 1 kg Li	185 km	(2)
Redwood	48 kg Ba + 1 kg Ba	250 km	(3)
Spruce	48 kg Ba	400 km	(1)

NOTE: (1) The Spruce payload was changed to a 185-km release altitude during the operation.

(2) Quince was a daytime release and the 1-kg Lithium canister was fired simultaneously with the 48-kg Ba to allow optical tracking.

(3) All 1-kg Ba canisters were fired at 185 km altitude on the downward leg of the trajectory.

Development of the neutral and ionized clouds of barium was studied by various experimental methods; diagnostic probes, RF beacons and ejection experiments were flown in rocket payloads, and extensive optical and RF diagnostic instrumentation were employed. An aircraft equipped with optical instrumentation gathered data looking up the magnetic field lines.

CHEMICAL PAYLOAD LAUNCH SCHEDULE

Test events occurred as shown in the following table. Changes from the original schedule were dictated by weather conditions at the test site and results obtained in early flights.

SECEDE II CHEMICAL PAYLOAD TEST MATRIX

Date	Event	Nominal Release Mass, Kilograms	Nominal Time From Ba Carrier Launch, Seconds	Radar Track (1) Release Alt. at Nominal Event Time, Kilometers	
16 Jan.'71	Nutmeg	48	101	150.5	
	Nutmeg	1	371	186.5	
20 Jan.'71	Plum	48	126	185.7	
	Plum	1	383	189.9	
26 Jan.'71	Redwood	48	188	255.6	
	Redwood	1	402	197.9	
29 Jan.'71	Olive	352	179	194.4	(2)
1 Feb.'71	Spruce	48	124	187.3	
2 Feb.'71	Quince	48 + 1(Li)	126	184.5	

NOTE: (1) Triangulation data and optical records are not available for precise confirmation of release time or release altitude. Altitudes listed are from vehicle radar track data at the nominal release time.

(2) The Olive payload malfunction resulted in an initial release mass of 288 kilograms followed by two additional 16-kilogram releases within the expanded volume of the initial release. A separate cloud was formed by a 16-kilogram release on the downleg of the rocket trajectory. This release occurred at approximately 298 seconds at an altitude of 187 kilometers.

PAYLOAD DESCRIPTION

48-Kg Payloads

All 48-kg barium-release payloads were flown on Terrier-Tomahawk two-stage vehicles. A nine-inch diameter aluminum payload housing provided structural support for the barium-release module components. The basic module includes three 16-kg canisters of barium thermite, the timing/firing set and monitoring circuitry for telemetered data. In addition, a canister and timing/firing set were included for the 1-kg downleg barium release on events Nutmeg, Plum, and Redwood. For payload Quince a lithium-vapor release was made using 1-kg of thermite which was initiated along with the three large barium canisters. A sketch of the 48-kg barium release payload is shown in Figure 1. A Sandia Laboratory (SLA) module containing radar beacon, telemetry, and second-stage fire set mounted to the head cap of the Tomahawk motor. The barium-release module was attached forward of the beacon module and at the opposite end provided a mating flange for the nose cone.

The timing/firing set was mounted on struts which extended into the nose cone and access for final checkout and arming was provided by removing the nose cone. As shown in the schematic of Figure 2, the firing circuit uses a capacitor discharge through an SCR to fire the Holex Model 3200 ignition squibs. The capacitors are charged in flight after closure of a barometric switch at an altitude of 20,000 feet. A pulse to the gate of the SCR, which initiates the capacitor discharge, is provided by a switch closure in the preset mechanical timer. Timer operation is started by the launch acceleration of the rocket. Two ignition squibs are provided in the barium canister, and two independent firing circuits are provided, each firing one squib in all canisters. (For payloads Nutmeg, Plum, Redwood, and Spruce, each half of the firing circuit initiated three squibs while in payload Quince a fourth squib was included in the Lithium canisters.) An essentially identical firing circuit has been employed successfully in eight previous SECEDE barium release payloads.

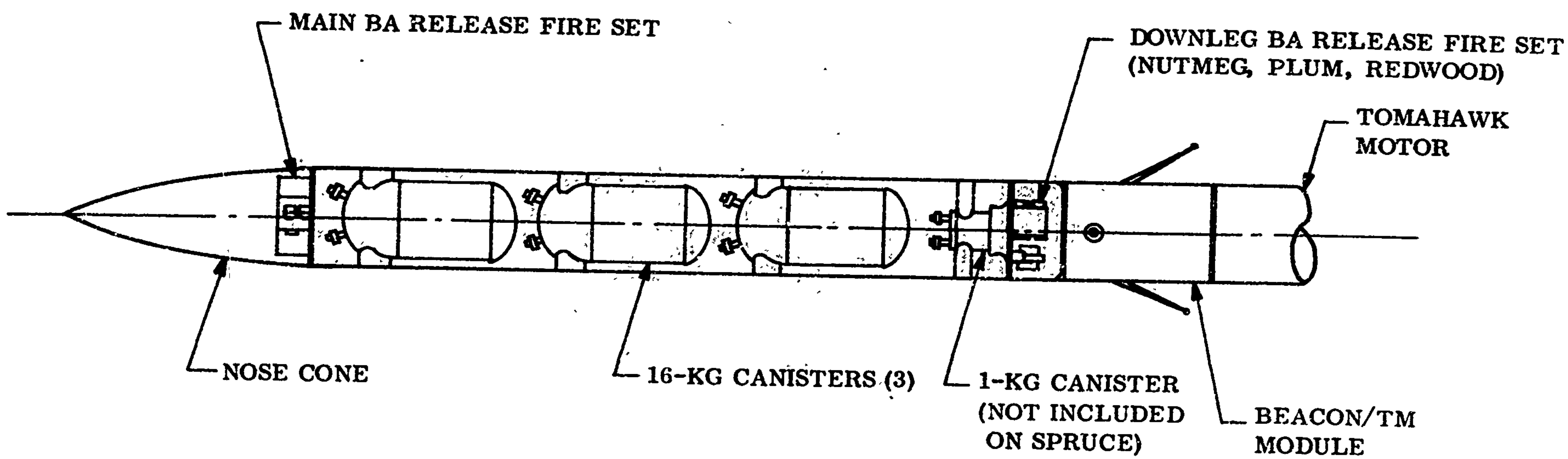

Figure 1. SECEDE II 48-Kg Barium Payloads

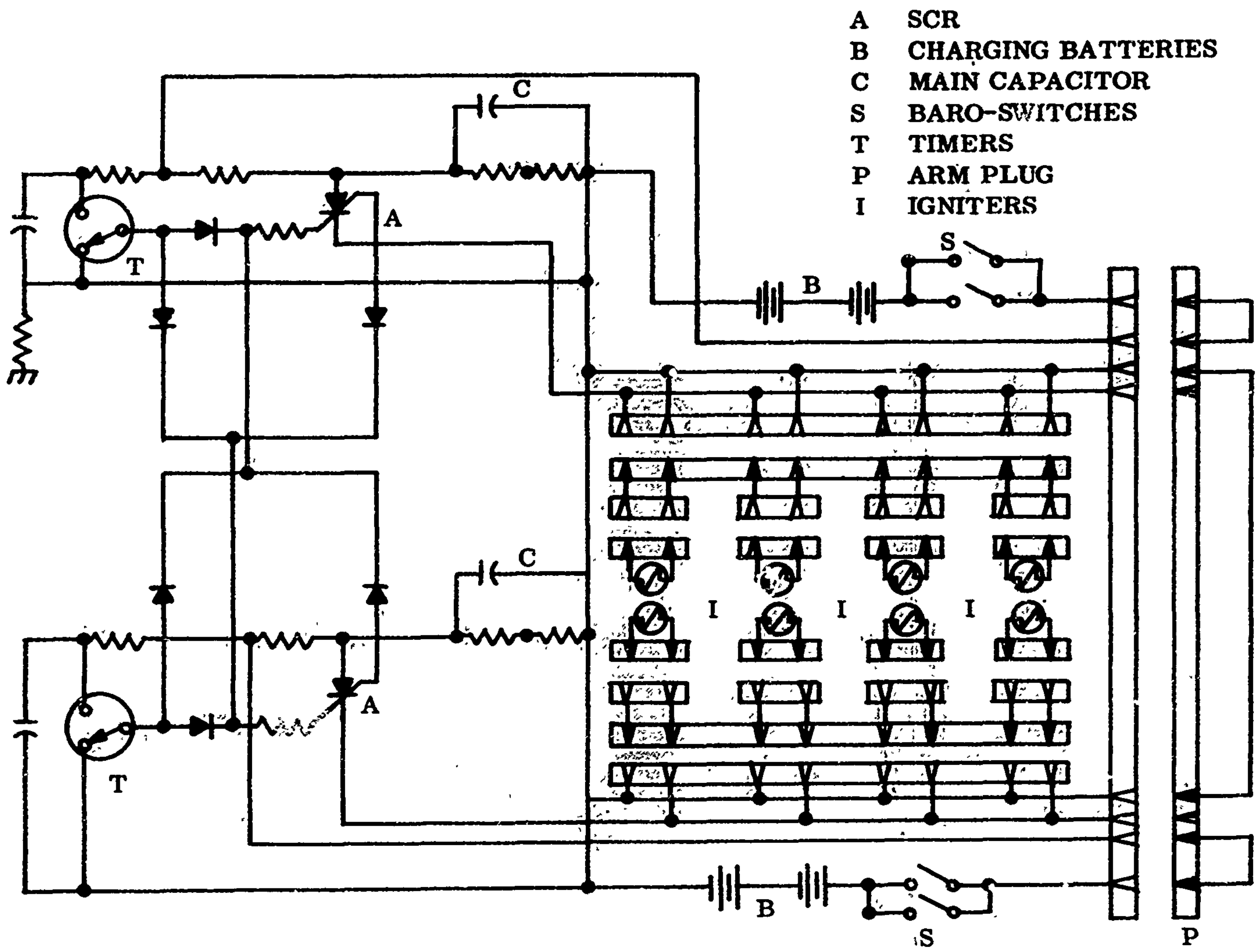

Figure 2. Electrical Schematic, SECEDE II 48-Kg Payload

The three 16-kg canisters mounted in the payloads aft of the firing set had two opposed nozzles which were aligned with open ports in the housing. One-kg dual-nozzle canisters were mounted in the same housing just behind the last larger canister. For the three payloads with downleg barium releases, an additional timing/firing set was mounted behind the 1-kg canister. An access port was provided for arming and final checkout of this second fire set which was functionally identical to the main fire set.

To monitor payload functions, an interface cable provided monitor signals to the SLA telemetry system and umbilical connector. For the main fire set, battery voltage was monitored prior to launch through the payload umbilical. During flight, capacitor voltage was monitored for the redundant circuits firing the three large canisters. Two pressure-actuated non-return switches were mounted in each 16-kg canister to provide a firing confirmation signal when the combustion pressure exceeded 100 psi. (Igniters firing into the canister without thermite ignition will not actuate the switch.) Actuation of the two switches in each canister was monitored on separate telemetry channels to provide a double indication of ignition for each canister. No remote monitoring was provided for the 1-kg releases since ground-based observations could confirm proper functioning.

352-Kg Payload

Payload Olive included 22 of the 16-kg canisters for a total of 352 kg of barium thermite. The STRYPI vehicle which carried the Olive payload provided a 31-inch diameter payload housing. In addition, the Olive payload included the barium canister mounting structure, the windscreen (ogival nose cone plus cylindrical external fairing), and an adapter section. A sketch of the Olive payload is shown in Figure 3.

The SLA adapter section carried the radar beacon, telemetry system, and windscreen ejection unit. It was attached to the STRYPI forward flange and provided structural support to both the windscreen and the barium mounting structure.

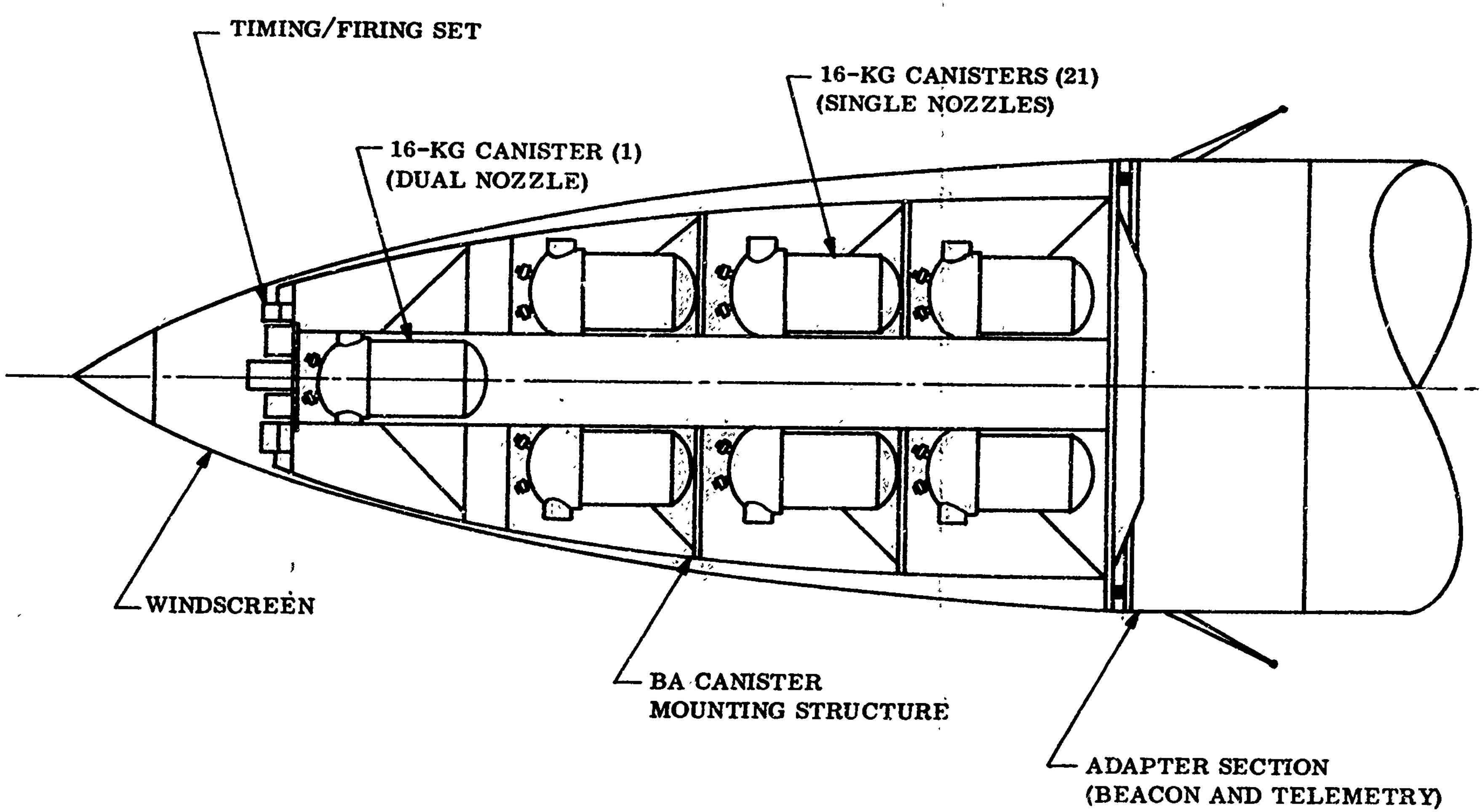

Figure 3. SECEDE II Payload Olive

Three thrustor units attached the windscreen to the adapter and were subsequently used in flight to release the windscreen and push it ahead of the vehicle thus exposing the barium canisters.

A fabricated-aluminum mounting structure for the barium canisters and fire sets was cantilevered forward of the adapter section to which it was attached. This structure was covered by the windscreen until the time of windscreen ejection which occurred well above the effective atmosphere. The primary structural members were a base plate for attachment to the adapter section and a central tube 10 inches in diameter. Three mounting decks spaced along the outside of the central tube each supported seven of the 16-kg canisters positioned symmetrically about the payload's longitudinal axis. Because of mounting constraints, these 21 canisters were fabricated with a single nozzle, but were otherwise identical to those used in the 48-kg payloads. Each canister's nozzle pointed radially away from the mounting structure. A twenty-second canister was located inside the support tube just ahead of the most forward deck of seven canisters, and it had two opposed nozzles which were aligned with exhaust ports in the central tube.

An electronics deck was provided at the forward end of the central tube and the timing/firing sets were attached to it. These components were accessible through the opening left by the removable nose tip of the windscreen. For the Olive payload, the intended simultaneous ignition of 22 canisters dictated the use of multiple circuits similar to that described for the 48-kg payloads. Three redundant firing circuits were used; two provided firing energy for seven canisters each with the third firing igniters in eight canisters. Three mechanical timers were used for redundancy but to better assure simultaneity the three firing circuits were interconnected by the regenerative gates of the SCR's so that the first timer to provide a triggering pulse initiated the discharge of all capacitors. With the exception of this interconnection and the number of squibs to be fired, firing circuits were identical to those of the smaller payloads.

Remote monitoring of payload status was also similar to that for the 48-kg payloads with umbilical readout of battery voltage and

in-flight telemetering of fire-set capacitor voltage. Fourty-four pressure actuated switches, two in each canister, were connected to the telemetry system to confirm canister ignition. Two commutated channels were used with each channel carrying one of the switch inputs from all canisters.

Chemistry

For SECEDE II barium releases the thermite materials were processed and loaded in the same manner as used in the Lime payload of PRE-SECEDE.

Material analyses indicate a barium metal purity of 98.5 percent and a cupric oxide purity of 91 percent. For the barium, principal impurities other than barium oxide were silicon, strontium, and calcium; traces of manganese, magnesium, iron, copper, and aluminum were also noted. Cuprous oxide and copper were the major impurities in the cupric oxide sample and traces of iron and aluminum were also noted.

The chemical formulation for the barium thermite is based on the reaction of 2.5 moles of barium per mole of cupric oxide according to the formula

$$2.5\ Ba + CuO \longrightarrow BaO + Cu + 1.5\ Ba.$$

In the SECEDE II payloads, 1.8 percent of the thermite weight was barium azide added to increase the combustion pressure by yielding nitrogen gas as it undergoes thermal dissociation. The desired combustion pressure between 1000 and 1200 psi has been confirmed in ground tests of this thermite system. A typical combustion chamber pressure trace is shown in Figure 4. The barium vapor yield from this exothermic reaction could theoretically be as high as 17.5 percent by weight, but most field test data indicate yields are probably less than five percent. A few measurements have noted yields on the order of 10 percent so the exact value is not known. Data gathered during SECEDE II may provide additional insight into this question. Composition of the barium thermite is described in the following table.

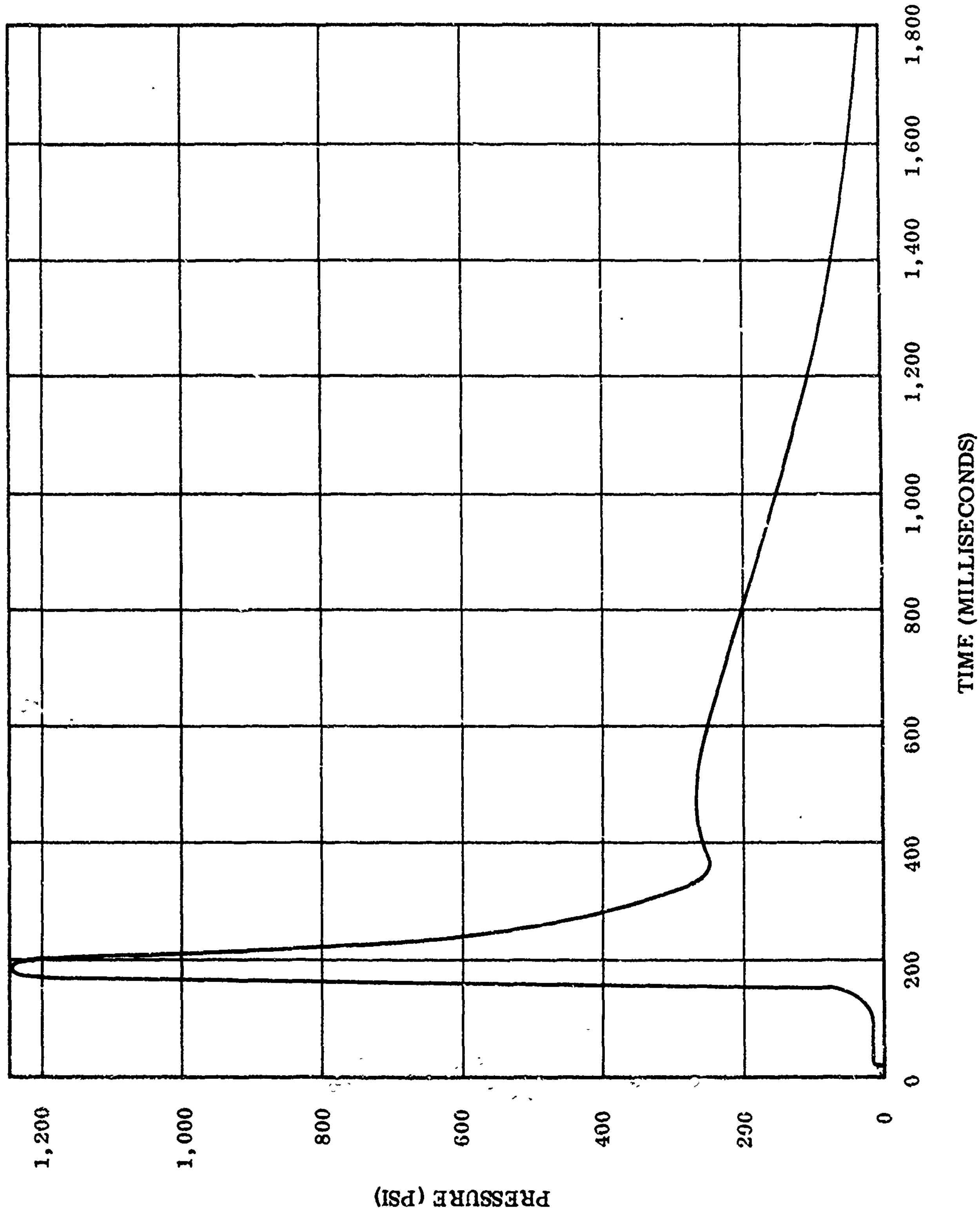

Figure 4. Pressure-Time Profile (16-Kg Ground Test)

BARIUM THERMITE FORMULATION

Total Chemical Weight	16-Kg	1-Kg
Composition by weight, percentage		
Barium Azide, $Ba(N_3)_2$	1.8 (.288 Kg)	1.8 (.018 Kg)
Barium Metal, Ba	79.8 (12.768 Kg)	79.8 (.798 Kg)
Cupric Oxide, CuO	18.4 (2.944 Kg)	18.4 (.184 Kg)
Excess barium available, Moles	55.9	3.5
Weight percentage	47.8 (7.652 Kg)	47.8 (.478 Kg)
Equilibrium reaction temperature at 1000 psi combustion chamber pressure, ^{o}K	2560	2560

Proper and consistent processing of materials utilized in the thermite is essential. The barium metal, which is generally shipped under oil, is cleaned and handled in an argon environment to prevent oxidation. After cleaning with benzene the material is thoroughly dried. The barium and oxidizer are mixed in small samples and pressed into the canister in layers. Barium metal is processed as chips, 2.5 millimeter $\pm$ .5 millimeter in diameter, while the oxidizer is a finer powder with a nominal particle size of .25 millimeter. The mechanical pressing operation results in a porous thermite grain with a density of 2.8 $\pm$ 0.1 grams-per-cubic-centimeter.

For the lithium vapor generator used in payload Quince, a 1-kg pressed-solid grain was loaded in a manner similar to that described for the barium thermite. A 30 percent theoretical yield of lithium vapor (42.9 moles) was computed for the reaction. The thermite contained the following weight percentages of reactants.

LITHIUM THERMITE FORMULATION

Component	Weight Percentage
Lithium	36.4
Lithium Nitrate	41.6
Lithium Perchlorate	8.1
Zirconium	13.9

All 16-kg canisters were ignited using the TU-121 igniter booster shown in Figure 5. In this booster initiation of the Holex Model 3200 squib starts the booster propellant grain, TPH #1016. The intense exhaust flame impinges on the surface of the barium thermite and is sufficient to start the thermite reaction. For the 1-kg canisters of barium and lithium thermite, the Holex 3200 squib was fired directly upon the thermite grain without using the booster.

Combustion Canister

The combustion canisters contain the pressed chemical thermite and are fabricated to provide the exhaust nozzle for venting reaction products as well as mounting provisions for the two igniters. SECEDE II 16-kg canisters also included mounting bosses for the pressure-actuated monitor switches shown in Figure 6.

Material used in the barium canisters is chosen for compatibility with the thermite chemicals during handling and to minimize contamination during combustion. The canisters are made of AISI 4130 steel with an asbestos-filled epoxy insulating material lining the inside.

Simple convergent nozzles are provided to vent the combustion products. The nozzle is formed by a graphite insert which is sealed by a thin brass closure during shipping and handling. The closure is blown away early in the pressure rise following ignition. Exit areas for the nozzles are selected to control peak combustion pressure in the canister. Approximately ten percent increase in nozzle diameter

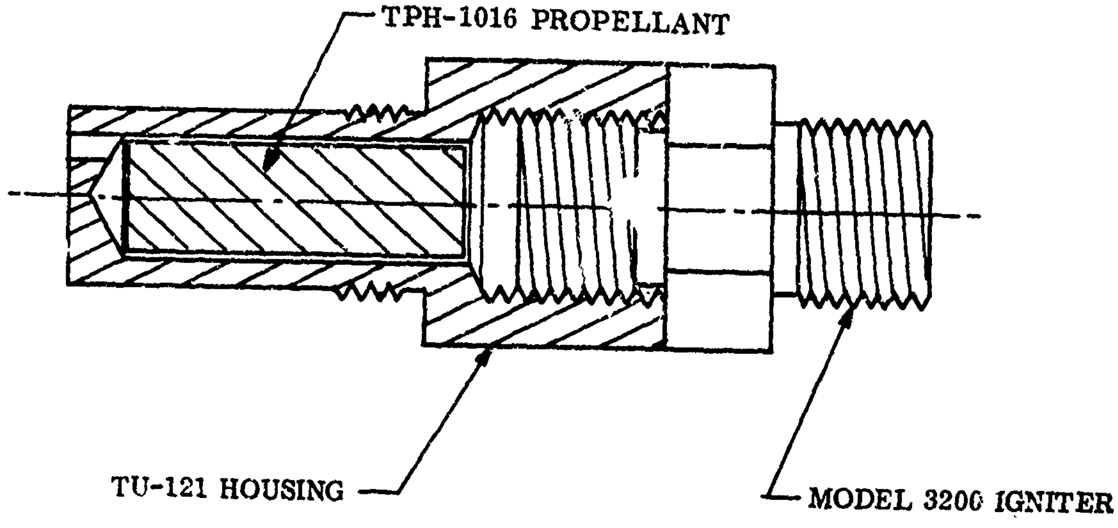

Figure 5. TU-121 Igniter Booster

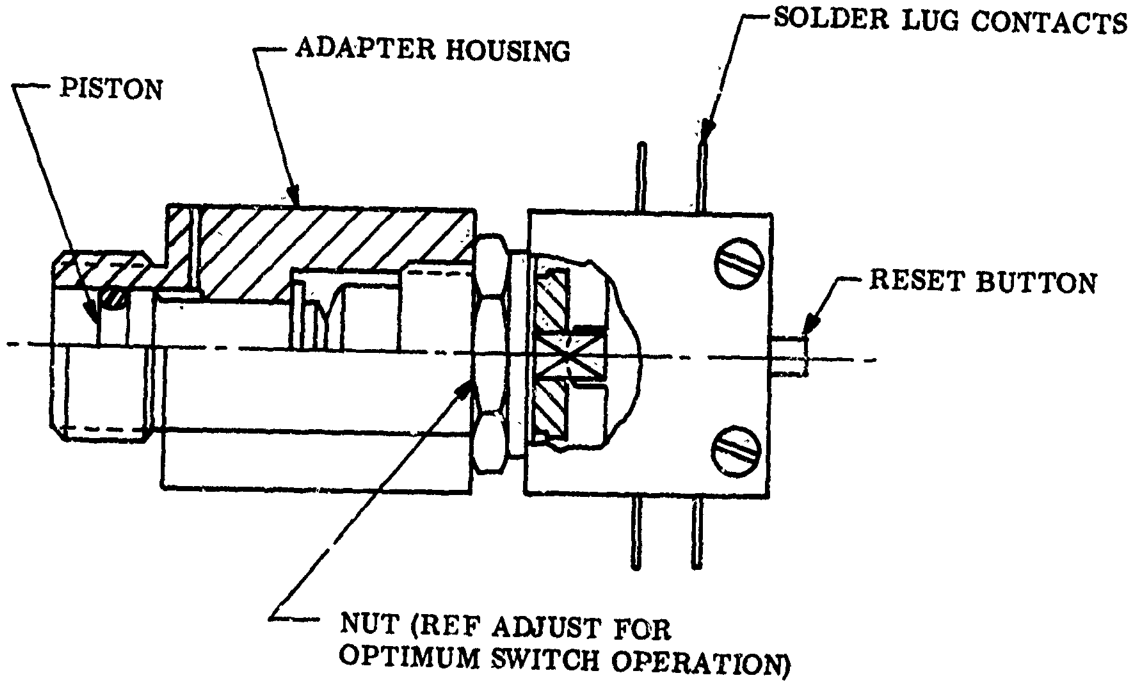

Figure 6. Pressure Switch Assembly

has been noted in ground tests due to graphite erosion. A sketch of the 16-kg canister is shown in Figure 7 and nozzle diameter data are presented below.

SECEDE II CANISTER NOZZLE DIAMETER

Canister	Nozzle Exit Diameter, in.
16-kg; two nozzles	1.0
16-kg; one nozzle	1.45
1-kg; two nozzles	.31
1-kg; two nozzles (Lithium)	1.06

After loading the thermite in the bottom half of the canister a head cap is threaded onto the lower half sealing the container which then contains argon gas at one atmosphere pressure. The head cap provides a plenum volume amounting to 25 .ercent of the total canister volume. Nozzles, igniters, and monitor switches are mounted in the head cap.

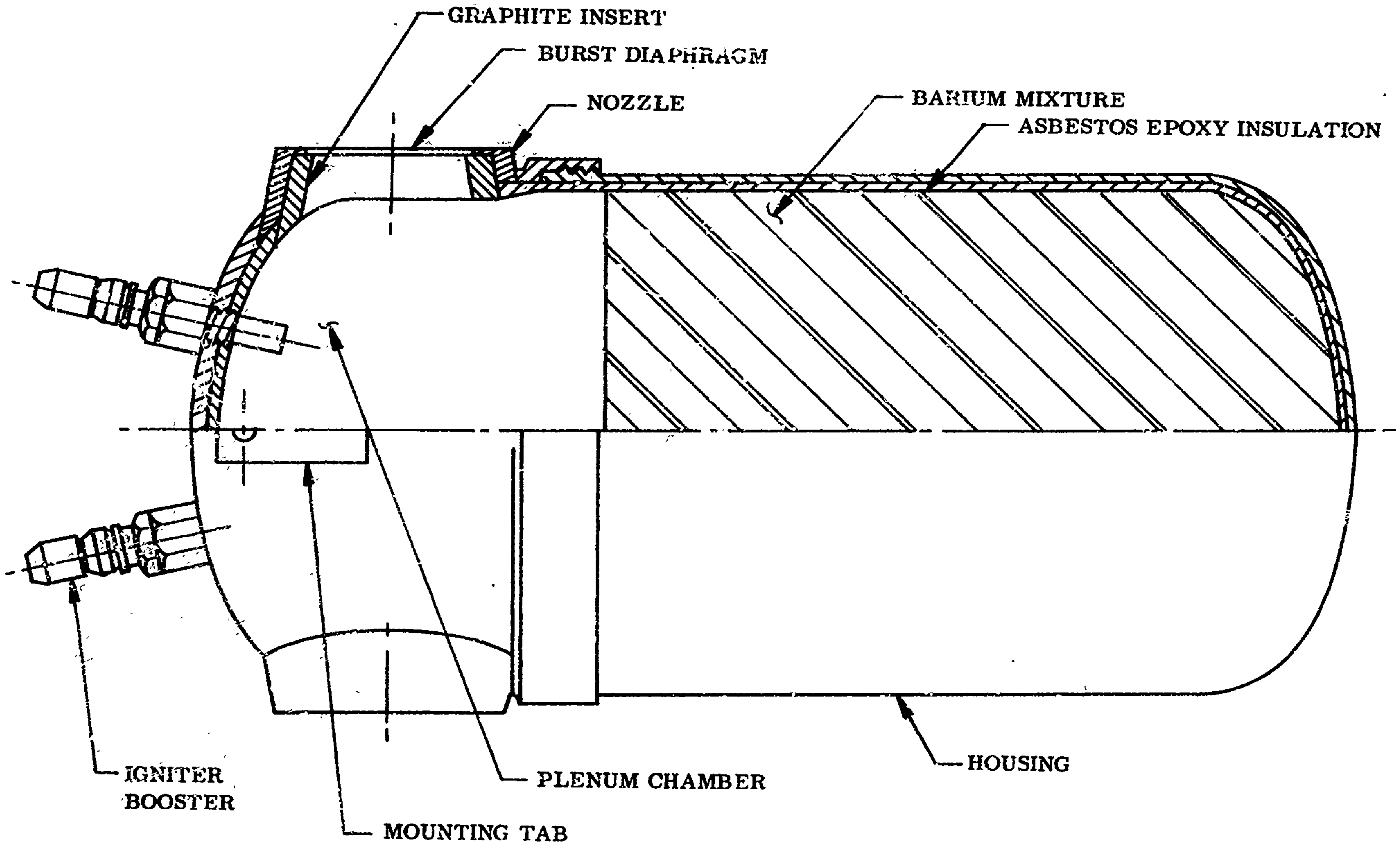

Figure 7. SECEDE II 16-Kg Canister

ASSEMBLY AND LAUNCH PREPARATION

As each payload was assembled it was subjected to a series of functional checks. The timing/firing sets were run several times to demonstrate proper operation with live squibs fired by each set at least once.

Assembly of the 48-kg payloads was completed at Thiokol's plant before shipment. Final connection of flight battery packs and firing harness took place at Eglin Test Site following a repeat of functional tests for the timing/firing set. The barium-release module was mated with other payload modules and transported to Site A-15 for loading on the launcher. The payloads were generally left on the launcher with rain covers between terminated countdowns until launched. Arming was performed per the countdown schedule and the payloads were disarmed following flight cancellations.

No preflight environmental tests were performed on the 48-kg payloads and they were not spin-balanced. The payload's mass symmetry and previous successful flights of similar payloads provided sufficient background to substantiate the design.

The Olive payload, 352-kg, was a new design and thus required significant environmental testing prior to flight. Components were shipped to SLA, Albuquerque, for assembly and integration. To reduce hazards during these tests, dummy canisters were used in place of the loaded barium canisters. Testing included: measurement of weight, C. G., and mass properties for the assembled payload; centrifuge tests to demonstrate structural capability under flight acceleration; and vibration testing. Following tests, the loaded canisters were mounted and the payload was shipped to Florida partially assembled. At the test site igniter squibs were installed and assembly was completed.

In addition to the normal series of functional tests, the Olive timing/firing circuitry was checked by firing a set of 44 "one-amp/one-watt" squibs. With complete success in this test, the payload was shipped to Albuquerque. Following environmental testing at SLA, another confidence test was made by firing 44 one-ohm bridgewires with

the fire set. At the test site prior to final assembly, a third test firing of 44 bridgewires was successfully completed.

Telemetry monitoring circuits were checked out and calibrated by operating the system while a simulated sequence of flight events was performed. Satisfactory operation was observed for the capacitor voltage monitoring circuit on all payloads and for each of the 44 pressure-switch firing indicators on payload Olive. Pressure switch operation was simulated on the 48-kg payloads as the switches were not accessible for tests.

Integration, assembly, and launch operations for all barium payloads were performed with no significant difficulties.

TEST RESULTS

From an operational standpoint all of the 48-kg payloads along with their secondary releases performed nominally. Precise time and position for the releases will be available in other reports, but the preliminary results indicated the release events were reasonably close to preflight predictions.

Telemetry operation confirmed firing of all canisters in the 48-kg payloads. A characteristic noted in all flights was a burst of noise on the telemetry signal shortly after the barium release was confirmed which cleared up one or two seconds later. Payload Quince was an exception in that a clear telemetry signal was never regained.

Payload Olive did not perform as anticipated in that the primary barium release was followed at significant intervals by three smaller releases. This anomally was observed visually and is verified by the noise burst on telemetry records. Rough estimates of the times for these four releases obtained from the telemetry records are 179, 188, 198, and 298 seconds after launch. Visual observations indicate releases 2 and 3 were within the expanded volume of the initial release while release 4 formed a separate cloud as the rocket was descending.

This unexpected result is not explained by the telemetry record in that capacitor voltage buildup, to 84 volts, appears normal as does the initial capacitor discharge. The second and third releases correspond to later capacitor discharge events as the firing circuit continued to cycle through charge-discharge sequences triggered by the SCR cut off and firing voltages. The fourth release does not correspond to a capacitor discharge event.

The canister monitor signals on the commutated telemetry channels provide ambiguous results as all positions did not make full scale changes on the record as programmed. Comparing the redundant records, since two monitors were located in each can, the best assessment is that 18 16-kg canisters were fired during the initial release followed by the three unexpected releases which consisted of one 16-kg canister each. One canister apparently did not fire.

Proper separation of the windscreen is indicated as the capacitor firing the three separating thrustors discharged at the appropriate time. No disturbance is noted on other telemetry records during the separation event.

POST FLIGHT TESTS

Additional tests have been conducted in an attempt to understand the mishap with the Olive payload. A firing circuit using identical components to those flown was fabricated and tested. The test unit had eight squib firing leads with lengths similar to those in the payload.

Results of these tests confirm that the design should perform properly and do not explain the difficulty experienced. With the post test work and review of previous experience, the following points were checked:

a. Does the fire set have sufficient energy to fire eight Holex 3200 squibs?

Squibs were fired in the test unit at voltages as low as 21 volts confirming previous experience with this system and indicating a factor of safety on energy of about 16:1. Other confirmation is provided by the preflight testing conducted with the Olive payload and with the successful use of similar capacitor systems on SECEDE III payloads where eight canisters were ignited simultaneously. During the Olive flight telemetry indicates the capacitors reached full charge.

b. Does the circuit imbalance prevent firing of some squibs?

Squibs were fired at 60 volt capacitor charge while one squib lead was shorted in post-flight tests. Preflight simultaneous ignition of 44 bridgewires was demonstrated three times with the Olive system.

c. What is the likelihood of a squib misfire?

The Holex Model 3200 has been used successfully by Thiokol in more than 100 in-flight barium-vapor cloud releases. To date no squib misfires have been noted in

flight or ground tests. The likelihood of two squib misfires occurring in one canister is judged remote. All squibs were checked for proper bridgewire resistance both before and after installation in the barium canisters.

d. What is the likelihood of the thermite failing to ignite or igniting late?

Experience is the main evidence opposing this possibility. No problem was noted in ignition of the 15 16-kg canisters flown in the 48-kg payloads to the same range of release altitude. Canisters for the Olive payload were loaded with the same materials in a random manner. Ignition difficulties have not been experienced with the barium thermite in previous flight programs or ground tests.

e. Could a canister burn through or rupture create the observed difficulties?

Because of successful use of this 16-kg canister design through at least 25 firings, a canister failure is not considered a likely event. However, the timing of the ignition sequence is much faster than the combustion pressure rise in the canister leading to the conclusion that in a normal performing system all the canisters would be fired before a rupture could damage the firing circuitry.

It is concluded that the design and functional testing of the Olive system confirm its capability to perform as intended. Therefore, damage of some type is assumed to have caused the firing circuit malfunction. No evidence is available to identify the source of this damage, but failure due to environmental effects such as vibration or due to damage during the windscreen separation are possibilities.